Renewable and Sustainable Energy Reviews 15 (2011) 2960–2973

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Renewable energy in Kenya: Resource potential and status of exploitation

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ARTICLE INFO

Article history:

Keywords:
Renewable energy
Review
Kenya
Africa

ABSTRACT

This paper presents an assessment of renewable energy resource potential and the current status of exploitation in Kenya. As an importer of petroleum fuels, Kenya spends a substantial amount of foreign reserves to import oil. The oil import bill in 2008 consumed 55% of the country's foreign exchange earnings from exports. On the other hand, there is a high dependence on wood biomass energy, leading to an imbalance in its supply and demand. This has exerted considerable pressure on the remaining forest and vegetation stocks, thereby accelerating the processes of land degradation. Moreover, despite the abundance of potential and a strong growth in demand for electricity, the country faces constraints in satisfying electricity demand. At the national level, only 18% of the households have access to grid electricity. The access is much lower in rural areas where only 4% of the households have grid electricity. Kenya has a liberalized energy sector and has made significant progress in the recent past in formulation of renewable energy policies. What is more, Kenya's electricity power mix is among the most sustainable in the world, with 80% of electricity coming from renewable sources. However, a substantial proportion of renewable energy resources are unexploited. Of the potential renewable sources, Kenya has harnessed only about 30% of its hydropower sources, approximately 4% of the potential geothermal resources and much smaller proportions of proven wind and solar power potentials. Furthermore, a large potential exists for the development of biomass based energy such as biogas, biodiesel and power generation form baggasse. The strong growth in energy demand provides excellent opportunities for private investors to invest in renewable energy power generation.



**Contents**



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doi:10.1016/j.rser.2011.03.023

## 1. Introduction

### 1.1. Geographical and other physical information for Kenya

Kenya is located on the East coast of Africa. It lies on the equator and is bordered on the east by Somalia, Ethiopia is to the north, Sudan to the northwest, and Uganda directly to the west. The southwestern border of the country is marked by Lake Victoria, and to the south is Tanzania and Mount Kilimanjaro while the Indian Ocean lies to the south east. It is 582,646 $km^2$ and is the world's 47th largest country.

Most parts of Kenya enjoy a tropical climate but the temperature remains comfortably warm averaging about 22 °C throughout the year. It is relatively hot and humid at the coast, temperate inland and very dry in the north and northeast parts of the country. Some parts of the country experience an equatorial kind of climate especially the central highlands. There is plenty of sunshine all the year round; however, it is usually cool at night and early in the morning. The hottest period is from February to March and coldest from July to August. The average annual temperature for the coastal town of Mombasa (altitude 17 m) is 30 °C maximum and 22.4 °C minimum, the capital city, Nairobi (altitude 1661 m) 25.5 °C maximum and 13.6 °C minimum, Eldoret (altitude 2133) 23.6 °C maximum and 10.6 °C minimum, Lodwar (altitude 506 m) and the drier north plain lands 35.5 °C maximum and 24.3 °C minimum. The long rains occur from April to June and short rains from October to December.

The Great Rift Valley divides the Kenya Highlands into east and west. Mount Kenya is on the eastern side. The Highlands are cool and agriculturally rich, where both large and small holder farming is carried out. Major cash crops are tea, coffee, pyrethrum, wheat and corn. Livestock farming is also practiced. The Lake Victoria Basin is dominated by Kano plains which are suited for farming through irrigation. The northern part of Kenya is plain and arid and pastoralism is the main land use activity, however, a variety of food crops do well through irrigation.

Kenya has diverse physical features which are a major source of tourist attraction. These include: vast plains which are home to world famous game parks and reserves; the Great Rift Valley, which runs north to south and whose floor has provided potential for geothermal power generation; Mount Kenya, the second highest mountain in Africa which is about 5199 m above sea level; Lake Victoria, the largest freshwater lake on the continent and which supports the fishing industry in the East Africa region; Lake Nakuru, another tourist attraction because of its flamingos; Lake Magadi, famous for its soda ash; and a number of major rivers, including Tana and Athi, Sondu-Miriu, which provide the hydropower resources of the country; Yala, Nzoia and Mara, the major feeders into Lake Victoria. Along the coastal line are beautiful white sand beaches, with palm trees, blue seas and resorts with cool Martinis.

Kenya has the most developed economy in Eastern Africa. It is also the economic, commercial, and logistical hub of the entire East African region. The economy is heavily dependent on agriculture, which accounts for around 24% of GDP and 18% of wage employment in both agriculture and agro-based industries. Table 1 provides some of the key economic and social statistics, whereas, Table 2 gives the percentage contribution to GDP by activity, for 2004–2008.

## 2. Energy status

### 2.1. Overall energy consumption

There are three main sources of energy in Kenya. These are biomass, petroleum, and electricity, accounting for 74.6%, 19.1% and 5.9%, respectively. The total primary energy consumption in Kenya in 2007 (excluding fuel wood and charcoal) was 3.62 Mtoe. In the same year, the local energy produced as a percentage of the total energy consumed was 10.9%. In Kenya, like many developing countries, the non commercial biomass plays a big role in energy supply especially to the domestic/residential sector (Fig. 1). The transport, agriculture, commercial and industrial sectors rely mainly on commercial energy, especially petroleum fuels and electricity. A small

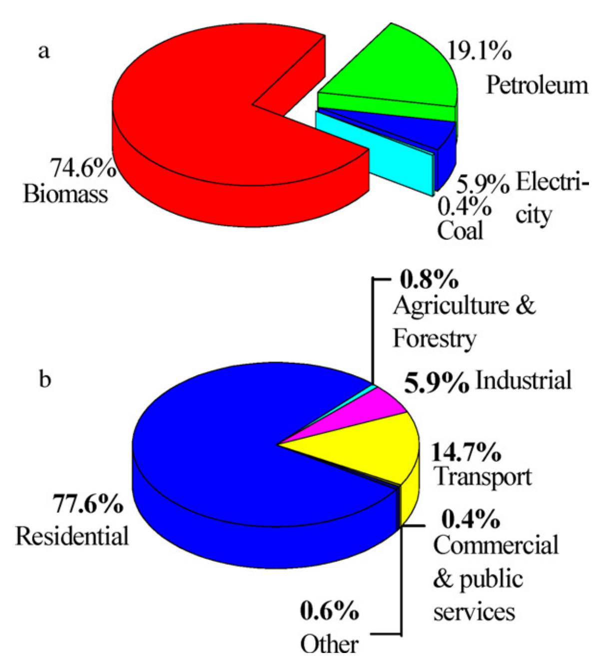



Fig. 1. (a) Energy supply in Kenya by type. (b) Energy consumption by sector [4].

**Table 1**
National statistics of Kenya.

| Indicator | Unit | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|
| Population | Million | 34.2 | 35.1 | 36.1 | 37.2 | 38.3 |
| Electricity consumption | GWh | 4234.1 | 4498.4 | 4752.4 | 5156.6 | 5352.2 |
| Petroleum consumption | ’000 tonnes | 2374.6 | 2715.9 | 3038.2 | 3121.8 | 3133.1 |
| GDP | USD (billion) | 16.1 | 18.8 | 22.5 | 27.0 | 34.5 |
| GDP growth rate | % | 5.1 | 5.9 | 6.3 | 7.1 | 1.7 |
| GDP per capita | USD | 482 | 556.7 | 656.9 | 783.8 | 706.4 |
| Total energy consumption | ’000 Toe | 2853.7 | 3155.2 | 30508.8 | 3627.1 | 3617.1 |
| Energy consumption per capita | Kgoe | 83.4 | 89.9 | 97.2 | 97.5 | 97.2 |
| Life expectancy at birth | Years | 44.94 | 47.99 | 48.93 | 55.31 | 56.64 |

*Source*: [1,2].

**Table 2**
Percentage contribution to GDP by activity, 2004–2008.

| Sector | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|
| Agriculture | 24.4 | 23.8 | 23.4 | 21.6 | 23.4 |
| Manufacturing | 10.0 | 10.5 | 10.3 | 10.4 | 10.6 |
| Electricity and water supply | 1.9 | 2.0 | 1.8 | 1.5 | 1.5 |
| Construction | 3.8 | 4.0 | 3.9 | 3.8 | 3.8 |
| Wholesale, Retail and Repairs | 9.2 | 9.2 | 9.3 | 9.7 | 10.0 |
| Hotel and Restaurants | 1.3 | 1.4 | 1.5 | 1.6 | 1.1 |
| Transport and communication | 10.9 | 10.3 | 10.6 | 10.6 | 10.2 |
| Financial Intermediation | 3.5 | 3.5 | 4.0 | 4.7 | 4.7 |
| Real estate, renting and Business services | 5.7 | 5.6 | 5.4 | 5.3 | 5.1 |
| Public administration and defence | 4.2 | 4.5 | 5.4 | 5.8 | 5.0 |
| Education | 7.9 | 7.4 | 7.0 | 6.8 | 6.3 |
| Health and Social work | 2.6 | 2.6 | 2.5 | 2.5 | 2.4 |
| Other Community, social and personal services | 3.9 | 3.8 | 3.6 | 3.5 | 3.4 |

*Source*: [1,3].

quantity of coal averaging about 0.1 Mtoe is imported annually for use mainly by cement producing companies.

### 2.2. Electricity

Grid electricity is the main source of modern energy in Kenya. The major sources of electricity are hydropower, thermal and geothermal. The total installed electric power generation capacity as at September 2008 was 1345 MW (Table 3), comprising of a mix of hydropower, oil thermal, geothermal, cogeneration from sugarcane baggasse and wind generation. It is worth noting that the percentage contribution of renewable energy to the national grid is about 80%, which makes Kenya’s electricity among the most sustainable in the world. The thermal generation consists of independent power producers (IPP), Emergency power plant (EPP), and isolated power units. The emergency power plant is mainly to mitigate the effect of fluctuations in hydro power due to poor rainfall. Isolated power stations (IPS) serve electricity loads away from the interconnected grid. The Kenya Government has developed several IPS to serve district headquarters and market centres in Lodwar, Marsabit (designed as a wind-diesel hybrid plant), Moyale, Mandera, Wajir, Garissa, Lamu, Mpeketoni, Hola, Merti and Habaswein. A further four IPS are being developed at El Wak, Pate Island, Mfangano Island and Baragoi.

There are four IPPs operating in the country namely Iberafrica (56 MW), Tsavo Power (74 MW), Orpower4 (48 MW), Mumias (2 MW) and one EPP namely Aggreko with a generating capacity of 150 MW. The Kenya Electricity Generating Company (KenGen) is the largest power generator in the country accounting for 75% of the total installed capacity.

The total effective capacity is 1302 MW (excluding isolated power units) during normal hydrology, against a suppressed peak demand of 1072 MW. The actual demand is estimated to be in the region of 1180 MW and is projected to grow at an annual rate of 7% to reach 2263 MW in the next 8 years [5]. In the recent past, inadequate rainfall experienced in the catchment areas for the water used in electricity generation has led to increased dependence on thermal generation. Thermal plants rely on expensive imported petroleum fuel, which leads to high cost of electricity. The high cost has had negative impact on economic activities in agriculture, manufacturing and transport sectors [3].

The annual electricity consumer connections have continued to rise sharply over the last four years, increasing from 67,105, 122,080, 140,807, and 201,194 in 2005/6, 2006/7, 2007/8, and 2008/9 financial years, respectively. The total number of customers connected to electricity was 1,109,248 as of September 2008 representing 18% access, which still compares poorly to the average of 32% for developing countries. In the rural areas, electricity access is estimated to be about 4%. The mean annual electricity consumption per household is 844 kWh in urban and 544 kWh in the rural areas, which translates to an average per capita consumption of 216 kWh and 115 kWh for the urban and rural households, respectively [6].

### 2.3. Petroleum products

Kenya does not have oil deposits, and relies entirely on imported petroleum products, either refined or in crude form. However, there has been oil exploration for a number of years at the coast and north eastern part of the country, and the prospects are promising. Imports of petroleum accounted for 36% of the total import bill in 2008 and consumed 55% of the country’s foreign exchange earnings from exports. The various petroleum products required for end use purposes mainly in transport, commercial and industrial sectors are; liquefied petroleum gas (LPG), kerosene, jet/turbo fuel, petroleum gasoline, diesel, fuel oil, and lubricating oils and greases. The total consumption of petroleum products in 2008 was 3.28 Mtoe, with retail outlets and road transport accounting for the highest consumption (Fig. 2). Most of the LPG used is produced at the Kenya Petroleum Refineries located in Mombasa. In rural areas, LPG is used along with firewood, while in urban areas, it is used as

**Table 3**
Installed capacity, effective capacity and annual production, 2007/08 [7].

| Sources | Installed capacity (MW) | Effective capacity (MW) | Share (%) | Annual production (GWh) | Share (%) |
|---|---|---|---|---|---|
| Hydro | 737.3 | 719.4 | 54.74 | 3488.00 | 60.12 |
| Thermal | 428.8 | 419 | 31.88 | 1253.00 | 21.60 |
| Geothermal | 163 | 163 | 12.40 | 1020.00 | 17.58 |
| Isolated power | 14.2 | 12.5 | 0.95 | 32.00 | 0.55 |
| Cogeneration | 2 | – | | 9.00 | 0.16 |
| Wind[a] | 0.4 | 0.4 | 0.03 | 0.2 | 0.00 |
| Total | 1345.70 | 1314 | 100 | 5802 | 100 |

[a] 5.1 MW wind farm was commissioned in August 2009.

a substitute to electricity. The average annual consumption of LPG is only 3.6 kg and 9.7 kg for rural and urban areas, respectively, or a national mean of 5.3 kg per household. The main reason for the low usage is due to the high cost of LPG based appliances. Problems related to transport and storage facilities for the commodity also make it unavailable in many parts of the country especially in the rural areas.

Kerosene is used by approximately 92% of all households (94% in rural and 89% in urban), mainly for lighting. The annual mean consumption is 90 litres and 41 litres in the urban and rural households, respectively. Many urban households use kerosene for cooking, hence accounting for the high urban consumption as compared to that in the rural [8]. In efforts to reduce deforestation associated to the high usage of fuel wood, Kerosene is exempt from some taxes in comparison to other petroleum fuels. However, inadequate distribution and retailing facilities in remote areas, has lead to high mark ups, making this commodity still expensive despite the tax exemption. Jet/turbo fuel is a market specific commodity, similar to Kerosene in composition but with a higher level of purity to avoid pollution. Its annual consumption in the recent years has been fairly constant at about 340,000 tonnes.

### 2.4. Operation and administration of energy sector

The organization structure of the power industry in Kenya comprises of the oversight bodies, the energy producers, and the transmission and distribution companies. The oversight bodies consist of the Ministry of Energy (MOE), Energy Regulatory Commission (ERC) and the Rural Electrification Authority (REA). The Kenya Electricity Generating Company (KenGen) and the Independent Power Producers are the main electricity generating companies, with KenGen being the main player (contributing 74% of the effective generating capacity, whereas the IPPs contribute the remaining 24% in 2008/2009). The Ministry of Energy provides the policy direction, prepares the least cost energy development plan for the country, and facilitates the mobilization of resources for the development of the power sector. Under the energy ministry there is the renewable energy department which consists of the following divisions: biofuels, solar, wind, mini/micro hydropower and energy conservation. The department runs 10 energy centres located in major ecological zones, through which renewable energy information is disseminated to, and also feedback is received from the public.

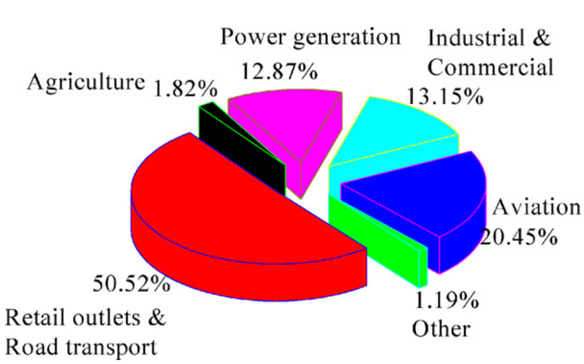



**Fig. 2.** Net Petroleum consumption per consumer category in 2007 [13].

The ERC was established under the Energy Act, 2006 to provide the technical, economic and environmental regulatory oversight to the industry, whereas the REA was commissioned in July 2007 and is responsible for implementing the Rural Electrification Programme, with the view of accelerating the implementation of projects lined up for implementation throughout the country. There is also the Energy Tribunal which arbitrates on disputes between the ERC and aggrieved stakeholders in the energy sector. The Kenya Power and Lighting Company (KPLC) undertakes transmission and distribution services buying power in bulk from KenGen and IPPs on the basis of long term power purchase agreements. The long-term power purchase agreements are based on "a take or pay basis" in line with international industry practice, whereby, the power generators are paid for capacity based on the performance of its plants against agreed targets. A new state owned company, Kenya Electricity Transmission Company Ltd. (Ketraco) has been formed, which is responsible for constructing new transmission lines. The creation of the company is intended to remove the financial burden from electricity customers of funding transmission projects capital investment costs.

### 2.5. Energy policy

In Kenya, the Ministry of Energy is in charge of developing and implementing energy policy to regulate the energy sector players and to ensure security and efficient utilization and conservation of energy. In the recent years, the ministry of Energy has developed various policies and regulations focused on promoting government priorities particularly to create an enabling environment for private sector led growth as well as increasing access and coverage of energy supply and promotion of renewable energy.

The first national energy policy [9] (Sessional Paper No. 4 of 2004 on Energy), which came into effect in 2004, contains specific measures to be undertaken by the government aimed at promoting the use of renewable energy. This policy was developed in response to service delivery survey of August 2002 which indicated a number of policy gaps within the Energy sector including lack of clarity on renewable energy, petroleum, geo-exploration and rural electrification. Moreover, new challenges in the now liberalised economy required new policy measures. This policy sets out the national strategies for the short-term, medium-term and long-term that will ensure adequate, quality, cost effective and affordable supply of energy to meet the development needs while protecting the environment.

The following institutional and legal reforms embedded in the Sessional Paper No. 4 are the main focus for implementation in the government's mid-term plan (2008–2012):

- Formation of a Geothermal Development Company to undertake resource assessment (this has already been implemented).
- Transformation of KPLC into a government owned transmission company and private sector led distribution company.
- Establishment of a Centre of Excellence for energy efficiency and conservation.
- Establishment of energy equipment testing laboratories.
- Development of standards and codes of practice on cost-effective energy use.
- Amendment of building by-laws under the Local Government Act Cap 265, in collaboration with the Local Government in order to make it mandatory to incorporate solar hot water systems in urban building designs.
- Expand improved stoves and charcoal kiln programmes, to reduce the fuel wood deficit to 5 million metric tonnes by the year 2012.
- Formulate strategies for attaining the target of 300 MW of co-generation capacity by 2015 and incorporate the same in the least cost power development plan.

In December 2006, the Energy Act 2006 was introduced, which seeks to amend and consolidate the laws relating to energy, to provide for the establishment, powers and functions of the Energy Regulatory Commission and the Rural Electrification authority and for connected purposes [10]. This Act provides for a more flexible licensing system, including small generating systems and for distribution and bulk sale by IPPs. In addition, the Act brings regulation and enforcement of energy sector activities under one body, the ERC. Moreover, clearer ways of promotion and development of renewable energy, enhancing energy efficiency and conservation are included in this act.

Recently, the Kenyan government formulated a feed-in-tariffs policy for wind, small hydros and biomass resource generated electricity [11]. The aim of this policy is to attract private sector investments in electricity generation from renewable energy sources as a means of diversifying national power sources, enhancing national energy security, creating employment and income generation. This policy allows power producers to sell and obligates the distributors to buy on a priority basis all renewable energy sources generated electricity at a pre-determined fixed tariff for a given period of time. A new tariff, which targets geothermal investors was recently introduced to guarantee a premium price of US8.5 cents/kWh (Sh6.60 under current exchange rates). Wind and biomass tariffs were also reviewed upwards from 9 US cents and 7 US cents to 12 and 8 US cents, respectively [12]. The objectives of the feed-in-tariffs policy are to:

(a) facilitate resource mobilization by providing investment security and market stability for investors in renewable energy sources (RES) electricity generation;
(b) reduce transaction and administrative costs by eliminating the conventional bidding processes, and
(c) encourage private investors to operate the power plant prudently and efficiently so as to maximize its returns.

## 3. Renewable energy resources and current exploitation status

Kenya is endowed with significant amount of renewable energy resources, which include: hydropower, geothermal, biomass, solar, wind, among others. In this section, a review on the available energy potential of the different renewable energy sources and the current status of exploitation is presented.

### 3.1. Biomass

#### 3.1.1. Biomass resources in Kenya

In Kenya, biomass energy resources are derived from closed forests, woodlands, bush lands, farm lands, plantations and agricultural and industrial residues. Table 4 shows the different sources of wood biomass and the annual approximate yields. Only 2% of the Kenya's land area is covered by forests, which supply about 45% of the biomass energy resources including wood wastes [13]. The remaining balance is derived from farm lands in the form of wood biomass as well as crop and animal wastes.

#### 3.1.2. Status of wood fuel and charcoal

Biomass in the form of wood fuel is the largest form of primary energy consumed in Kenya, accounting for 74% of the total national primary energy supply [4]. According to a comprehensive study completed in 2002, in 2000, wood fuel demand stood at 34.3 million tonnes compared to an estimated sustainable supply of 15 million, thereby indicating a deficit of over 56%. It is estimated that the deficit is currently at 60%. The wood fuel demand was estimated to be growing at 2.7% per year while the sustainable supply was growing at a slower rate of 0.6% per year [14]. In 2000, the average annual firewood consumption in both rural and urban areas was 3394 and 2701 kg per household, respectively. The corresponding per capita consumption was 741 and 691 kg, respectively. The principal drivers of wood fuel demand are population growth, lack of access to biomass energy substitutes and the growing incidence of poverty among the population. The wood fuel energy supply and demand imbalance is exerting considerable pressure on the remaining forest and vegetation stocks, thereby accelerating the processes of land degradation. In addition, the production of biomass energy poses a threat to competing land use systems such as agriculture, forestry and human settlements, among others.

On the other hand, charcoal is an important fuel particularly for urban dwellers. Its production is however associated with the increasing levels of deforestation. About 47% of the Kenya households use charcoal, with 82% of the usage in the urban households, and 34% in the rural households. On average, the urban charcoal consumption in 2000 was found to be 156 and 152 kg per capita for rural and urban dwellers respectively. The total charcoal production in the year 2005 was estimated to be 2.4 million tonnes (or 67 million bags of 36 kg each). The effective regulation of the charcoal industry remains one of the key challenges faced by the government now and in the future. Improved stoves programme initiated in 1981 under the auspices of the Kenyan Ministry of Energy as a

**Table 4**
Different sources of wood biomass and approximate annual yields.

| Source | Approx. size (ha) | Annual productivity ($m^3$/ha/year) | Approximate annual yield (Million $m^3$) | Accessibility (%) |
|---|---|---|---|---|
| Closed forests | 1,247,400 | 1.3 | 1.60 | 5 |
| Woodlands | 2,092,600 | 0.64 | 1.30 | 30 |
| Bushlands | 24,629,400 | 0.44 | 10.84 | 30 |
| Wooded grasslands | 10,600,000 | 0.25 | 2.60 | 30 |
| Grassland | 1,203,500 | 0.08 | 0.096 | 10 |
| Farmlands | 10,000,000 | 1.44 | 14.40 | 90 |
| Forest plantations | 91,000 | 19.9 | 2.70 | 35 |

*Source*: [13].



**Fig. 3.** Improved charcoal stoves [15].

means of conserving fuel wood led to the development of improved ceramic charcoal stoves popularly known as Kenya Ceramic Jiko (KCJ) (Fig. 3). These stoves have been widely disseminated and are being used in Kenya.

#### *3.1.3. Biogas potential and use*

Biogas is derived from anaerobic fermentation of biomass and solid wastes. The gas generated contains methane which is combustible and can be used to produce heat or electrical power. There is no actual data available on the biogas potential in Kenya. However, Felix and Kai [16] have made an assessment on the technical potential of domestic biogas systems to be 1.25 million households. The technical potential was defined as the numbers of households that have basic requirements of sufficient availability of dung and water. This potential can be much higher if other types of wastes are considered such as municipal wastes.

Biogas technology was introduced in Kenya in the mid 1950s by white settler farmers. Initially, two types of biogas systems were promoted viz.: the floating drum (Indian digester) and the fixed dome type (Chinese digester). Later in the 1990s a low cost Tubular Plastic (TP) bio-digester developed in Colombia was also introduced and has been widely promoted especially in Western part of Kenya [17]. In efforts to raise awareness and use of biogas and reduce demand on fuel wood, the ministry of energy demonstrated biogas production technology all over the country since the early 1980s. Various NGOs and Christian organizations have also been actively involved in dissemination and promotion of biogas technology. Despite its potential benefits, the penetration rate of biogas technology in Kenya is still very low. So far about 1392 family biogas plants (10 $m^3$) have been installed and each producing on average about 1.2 $m^3$ of biogas per day [13]. However, according to the Intermediate Technology Development Group (ITDG) (now Practical Action), approximately 1100 biogas units are operational in Kenya. The gas is used for cooking and to some smaller extent for lighting.

Widespread adoption of biogas systems has been hampered by lack of adequate information on its production, and potential benefits and also prohibitively high cost of earlier designs, and the fact that most households in the rural areas do not have piped water. The main problems reported are: poor maintenance, poor construction or design leading to gas pressure problems, high maintenance costs and weak technical support [18].

#### *3.1.4. Co-generation potential*

Co-generation using bagasse as a primary fuel is common practice in the domestic sugar industry in Kenya. The industry comprising seven sugar companies produces an average of 1.8 million tonnes of bagasse with fibre contents of about 18% by weight annually. Out of this quantity, about 56% is used in co-generation using an installed capacity of 25 MW and the balance disposed at cost. Mumias is the only sugar company among the seven factories that is self-sufficient in electricity production and has the capacity to export about 2 MW of surplus power to the national grid. Table 5 shows the estimated potention of power generation from bagasse. The government has intention to expand cogeneration investment programme to realize 300 MW target by 2015.

#### *3.1.5. Liquid biofuels*

Liquid biofuels are liquid energy sources derived from plant material. In Kenya, there is a high potential for production of bioethanol and biodiesel. Ethanol is an alcohol made by fermenting the sugar components of plant materials, mostly from sugar and starch crops, whereas biodiesel is produced from oils or fat using transesterification and is a liquid similar in composition to mineral diesel. These fuels are biodegradable and produce less toxic pollutants and greenhouse gases than petroleum-based fuels. Recently, a feasibility study on biofuels was conducted and the potential and challenges facing biofuels development in Kenya were identified [19]. In this study cassava, sugarcane, and sweet sorghum were identified as viable ethanol feedstocks, whereas castor, coconut, cotton, croton, jatropha, rapeseed and sunflower are potential viable feedstocks for biodiesel. Research done on yellow oleander plant (*Thevetia peruviana*) seeds at Jomo Kenyatta University of Agriculture and Technology shows to be a potential bio-diesel source [20]. The yellow oleander plant originally from

**Table 5**
Power potential from bagasse.

| Factory | | Chemelil | Muhoroni | Mumias | Nzoia | Sony | W-Kenya | Total |
|---|---|---|---|---|---|---|---|---|
| Cane crushing capacity (Ton/day) | Current | 2500 | 2200 | 7100 | 2600 | 3000 | 1320 | 18720 |
| | Potential | 7000 | 4000 | 9135 | 7000 | 6500 | 3500 | 37135 |
| Bagasse available (Ton/day) | Current | 950 | 800 | 2850 | 1090 | 1110 | 488 | 7288 |
| | Potential | 2660 | 1720 | 3650 | 2940 | 2405 | 1295 | 14670 |
| Power generation (MW) | Current | 10 | 9.8 | 32 | 14 | 15 | 5 | 85.8 |
| | Potential | 29 | 19.8 | 47 | 40 | 37 | 20 | 192.8 |
| Electrical energy generation (GWh) | Current | 48 | 35 | 214 | 52 | 74 | 25 | 448 |
| | Potential | 156 | 134 | 236 | 221 | 231 | 109 | 1087 |
| Internal usage (GWh/year) | Current | 14 | 7 | 52 | 11 | 16 | 5 | 105 |
| | Potential | 47 | 27 | 57 | 47 | 50 | 29 | 257 |
| Export (GWh/year) | Current | 34 | 28 | 162 | 41 | 58 | 20 | 343 |
| | Potential | 108 | 108 | 179 | 174 | 181 | 80 | 830 |

*Source*: [13].



**Fig. 4.** Jatropha carcus nursery with over 70,000 seedlings in Kariema (Baringo).

Peru in S. America grows well in Nyanza province. It is a perennial crop, drought resistant and requires minimum inputs during field cultivation and the seeds can yield 20% oil. Other benefits of this plant include: a good source of nectar for honey making since its flowers can flower throughout the year, source of firewood fuel, source of materials for furniture making and also the cake can be used as a source of animal feed or manure.

Interest in biodiesel was renewed by the high cost of oil experienced last year and now jatropha caucus plant is being tested in nurseries and farms in different arid and semi arid parts of Kenya (Fig. 4). The Kenyan government has shown great support for the development of biodiesel and has committed 500,000 acres of land for jatropha cultivation. Furthermore, a draft strategy for biofuels has been prepared and a blending of 3% biodiesel is proposed with the intention to reduce fossil fuel imports by 5% in the next four years [21].

### 3.1.6. Municipal waste

Municipal waste can be used to produce methane gas, which is then used to generate electricity. The technology for conversion of waste into electricity is mature and is used in various parts of the world. In the capital city of Kenya, Nairobi, solid waste to the tune of 803,000 tonnes a year is generated and dumped in Dandora Dump Site. Mombasa, Nakuru and Kisumu which are the major towns after Nairobi between them dispose 1124 million tonnes. Overall, it is estimated that a total of 5.26 million tonnes per year is generated in the urban centres in the country [22]. Municipal waste has not been exploited for energy generation and is often disposed through open burning.

## 3.2. Hydropower resources in Kenya

### 3.2.1. Large hydros

Kenya has a considerable hydropower potential estimated in the range of 3000–6000 MW. It is estimated that the undeveloped hydroelectric power potential of economic significance is 1509 MW, out of which 1310 MW is suitable for projects of 30 MW or bigger. This hydropower potential is located in five geographical regions, representing Kenya's major drainage basins as shown in Table 6. The average energy production from these potential projects is estimated to be at least 5935 GWh per annum.

### 3.2.2. Small hydros

Small hydro, mini and micro hydropower in Kenya (with capacities of less than 10 MW) is estimated at 3000 MW nationwide. Approximately 55 river sites have been identified with attractive commercial possibilities, with mean capacities in the range of 50–700 kW [24]. Most of the sites are situated in rural areas and are suitable for stand-alone systems for supplying power to small communities away from the grid. A number of pilot/demonstration mini and micro hydro projects have been implemented to assess the viability of such systems.

### 3.2.3. Existing hydropower projects

Currently over 709 MW of large hydropower and 31 MW of small hydropower have been exploited (Table 7 and Table 8) which contribute over 70% national annual electricity generation. These power plants are mainly owned by KENGEN, tea processing companies and missionary institutions. Furthermore, the government has developed the feed-in-tariff policy for the purpose of promoting the exploitation of small and mini hydro resources. The sessional paper on energy (2004) outlines strategies for promoting small hydro power development which include:

- Continuous collection of hydrological data.
- Undertake pre-feasibility studies of those sites commanding high economic merit and rank them.
- Create investor and consumer awareness on economic potential of small hydropower technology as an alternative source of energy.

## 3.3. Solar energy

### 3.3.1. Solar energy resource in Kenya

Kenya receives between 4 and 6 kWh/m$^2$/day. The country's annual average is about 5 kWh/m$^2$/day, equivalent to 250 million tonnes of oil equivalent (Toe) per day [25]. Table 9 gives the annual average Direct Normal Irradiation and the analyzed spatial areas, whereas Fig. 5 shows the annual sum of hourly Direct Normal Irradiation (DNI), averaged for the year 2000–2002. Kenya has high insolation rates with an average of 5 peak sunshine hours (The equivalent number of hours per day when solar irradiance averages 1000 W/m$^2$). The total amount of energy ranges from 700 kWh in mountainous regions to 2650 kWh in arid and semi-arid regions per year, with most parts of the country lying in the 1750–1900 kWh range. However, only an insignificant amount out of this vast resource is hitherto harnessed. Diverse application of solar energy include solar thermal for heating and drying and solar photovoltaic (PV) for lighting,

**Table 6**
Major hydro potential.

| River basin | Potential capacity (MW) | Average energy (GWh/year) | Firm energy (GWh/year) |
|---|---|---|---|
| Tana | 570 | 2490 | 1650 |
| Lake Victoria | 355 | 1680 | 1450 |
| Ewaso Ngiro North | 155 | 675 | 250[a] |
| Rift Valley | 345 | 630 | 300[a] |
| Athi Basin | 84 | 460 | 290 |
| Total | 1509 | 5935 | 3390 |

[a] Estimate source: [23].

**Table 7**
Existing large hydro power stations.

| Station | River located | No. of units | Rating per unit | Installed capacity (MW) | Supplier | Year installed | Age | Remaining economic life (years) |
|---|---|---|---|---|---|---|---|---|
| Kindaruma | Tana | 2 | 20 | 40 | AEI/Boving | 1968 | 40 | 10 |
| Kamburu 1and 2 | Tana | 2 | 31.4 | 62.8 | Litostroj/Rade Koncar | 1974 | 34 | 16 |
| Kamburu 3 | Tana | 1 | 31.4 | 31.4 | Litostroj/Rade Koncar | 1976 | 32 | 18 |
| Gitaru | Tana | 2 | 72.5 | 145 | Siemens/Voith | 1978 | 30 | 20 |
| Gitaru Unit 3 | Tana | 1 | 80 | 80 | | 1999 | 9 | 41 |
| Masinga | Tana | 2 | 20 | 40 | BBC/Escher WYSS | 1981 | 27 | 23 |
| Kiambere | Tana | 2 | 72 | 144 | Marine Industries Ltd | 1988 | 20 | 30 |
| Turkwel | Turkwel | 2 | 53 | 106 | Neyrpic/Alsthom Jeumont | 1991 | 17 | 33 |
| Sondu | Sondu | 2 | 30 | 60 | Toshiba/Mitsui | 2008 | <1 | 50 |
| Total | | 16 | | 709.2 | | | | |

*Source*: [13].

**Table 8**
Existing mini/micro hydro stations.

| Plant | | Year | Installed by | No. of units | Rating per unit (MW) | Total installed capacity (MW) |
|---|---|---|---|---|---|---|
| Ndula | | 1925 | KPLC | 2 | 2.000 | 2.000 |
| MESCO | | 1933 | KPLC | 1 | 0.380 | 0.380 |
| Selby falls | | 1952 | KPLC | 2 | 2.000 | 0.400 |
| Sagana Falls | | 1955 | KPLC | 3 | 0.500 | 1.500 |
| Gogo Falls | | 1958 | Mining Co. | 2 | 1.000 | 2.000 |
| Tana 1 & 2 | | 1932 | KPC | 2 | 2.000 | 4.000 |
| Tana 3 | | 1952 | KPC | 1 | 2.400 | 2.400 |
| Tana 4 | | 1954 | KPC | 1 | 2.000 | 4.000 |
| Tana 5 | | 1955 | KPC | | | 4.000 |
| Wanjii 1 & 2 | | 1952 | KPC | 2 | 2.700 | 5.400 |
| Wanjii 3 & 4 | | 1952 | KPC | 2 | 1.000 | 2.000 |
| James Finlay | 1 | 1934 | | 2 | 0.150 | 0.300 |
| James Finlay | 2 | 1934 | | 2 | 0.200 | 0.400 |
| James Finlay | 3 | 1980 | | 2 | 0.060 | 0.120 |
| James Finlay | 4 | 1984 | | 1 | 0.320 | 0.320 |
| James Finlay | 5 | 1999 | | 2 | 0.536 | 1.072 |
| Brooke Bond | 1 | | | | | 0.090 |
| Brooke Bond | 2 | | | | | 0.120 |
| Brooke Bond | 3 | | | | | 0.180 |
| Brooke Bond | 4 | | | | | 0.240 |
| Savani | | 1927 | Eastern Produce | – | | 0.095 |
| Diguna | | 1997 | Missionary | – | | 0.400 |
| Tenwek | | | Missionary | 1 | | 0.320 |
| Mujwa | | | Missionary | 1 | | 0.068 |
| Community MHPs | | 2002 | | – | | 0.017 |
| Total | | | | | | 31.822 |

*Source*: [13].

water pumping, crop drying, refrigeration and telecommunications.

### *3.3.2. Status of solar energy in Kenya*

A vibrant solar energy market has developed in Kenya over the years for providing electricity to homes and institutions remote from the national grid and for medium temperature water heaters for domestic and commercial usage. Kenya has the world's highest household solar ownership rate with about 30,000 small (20–100 W, per household) systems sold per year [27,28], and has attracted number of case studies [29–33]. Solar electric systems are being imported and sold to end users in Kenya through a competitive and growing free market network that includes more than 10 import and manufacturing companies, as well as hundreds of vendors, installers, and after sale service providers. In 2003, the cumulative sales were estimated to be in excess of 220,000 units (more than 4 MW). On the other hand, about 7000 solar thermal (about 140,000 $m^2$) are in use for drying of agricultural produce and water heating [34–36].

**Table 9**
Analysis of direct normal irradiation (DNI) available in Kenya.

| DNI ($kW/m^2/day$) | Area ($km^2$) | DNI ($kW/m^2/day$) | Area ($km^2$) |
|---|---|---|---|
| 3.50–3.75 | 41721 | 5.50–5.75 | 33848 |
| 3.75–4.00 | 61515 | 5.75–6.00 | 20211 |
| 4.00–4.25 | 140326 | 6.00–6.25 | 24675 |
| 4.25–4.50 | 177347 | 6.25–6.50 | 33690 |
| 4.50–4.75 | 137572 | 6.50–6.75 | 22468 |
| 4.75–5.00 | 96199 | 6.75–7.00 | 16240 |
| 5.00–5.25 | 62364 | 7.00–7.25 | 6736 |
| 5.25–5.50 | 48826 | 7.25–7.50 | 2656 |

*Source*: [13].

The government is currently implementing a solar PV electrification of schools and other institutions in selected districts, which are remote from the national grid as part of a national strategy to enhance the contribution of renewable sources of energy to the overall energy supply mix. By the end of 2009, about 150 public institutions were expected to have installed a total capacity of 360 kW of PV electricity, and the total capacity of all solar PV installations in rural areas of Kenya would be in the order of 6 MW [13].

Despite this success, the percentage contribution of solar energy to the total energy mix is insignificant (less than 1%).

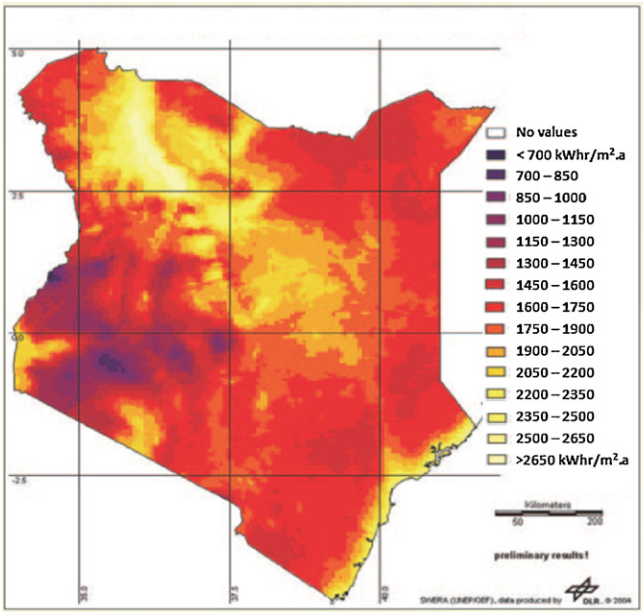



**Fig. 5.** Annual sum of hourly Direct Normal Irradiation (DNI) for Kenya (2000–2002 averaged) [26].

Solar powered cooling and refrigeration is another potential application of solar energy especially in remote areas where there is no grid electricity. Recently, ISAAC solar powered icemaker was introduced in two rural villages in coastal Kenya (Fig. 6). The ISAAC ice maker is based upon the intermittent ammonia/water absorption refrigeration technology and operates entirely without electricity.

## *3.4. Wind energy*

### *3.4.1. Wind energy resources in Kenya*

Kenya is located within the equatorial region which does not favor strong winds like those experienced in the extra-tropical regions, which are normally strong and persistent over long periods of time. However, various studies have shown that complex topographical features and the varying nature of surfaces in addition to the existence of large inland lakes have marked influence in modifying the horizontal and vertical wind speed profiles, thus making many locations to posses substantial wind energy potentials [38]. The Ministry of energy has developed a national wind atlas (Fig. 7) which shows that wind regimes in certain parts of Kenya (such as Marsabit, Turkana, Ngong and the Coastal region) can support commercial electricity generation as they enjoy wind speeds ranging from 8 to 14 m/s. Fig. 8 shows hourly and monthly wind speed variation at one of the high wind potential area (Marsabit).



**Fig. 6.** ISAAC solar ice makers installed in Kwale District for milk preservation [37].

### *3.4.2. Status of wind power development in Kenya*

Wind energy has been used in Kenya primarily for water pumping since the beginning of th19th century. However its use declined with the advent of oil fired internal combustion engines, which are flexible and more convenient to use. More than 220 Kijito wind pumps have been disseminated for use in various remote areas of Kenya [41].

There is little experience in the use of wind for power generation in Kenya, however the awareness and interest is steadily growing, motivated especially by the rising cost of oil, the surging demand for power, the effect of concurrent drought on hydropower and the need to address global warming. In August 2009, the first wind farm with a capacity of 5.1 MW was commissioned at Ngong Hills near Nairobi (Fig. 9). This grid connected wind turbines was financed by a Belgium government loan through the Kenya government consists of six turbines (height 49 m) rated 850 kW each and is expected to generate 14.9 GWh annually. This adds to the initial 0.35 MW turbines installed in 1993. An additional 200 kW stand alone wind-diesel hybrid system is operating in Marsabit. There are a number of well established companies that import and sell small wind generators and a limited number of small wind generators (1–5 kW capacity) have been installed for use in remote missions, farms and health centres in various places in Kenya.

Table 10 shows the planned wind projects to be developed. The construction of the biggest wind farm (300 MW) in Laisamis near Lake Turkana is expected to begin in January 2010. This will cost US$ 760 million and will be one of the biggest wind farms in Africa, projected to produce 1440 GWh electricity annually (about 26% of the current consumption) upon its completion in 2013.

## *3.5. Geothermal exploration and development*

### *3.5.1. Geothermal resources*

Kenya is endowed with enormous geothermal resources which are mainly located around volcanic centres within the rift valley. The unexploited geothermal power potential is estimated to be in the range of 4000–7000 MW [43]. Fig. 10 shows the prospective sites for geothermal energy in the Kenyan Rift Valley. Explorations in some of the areas have been done, and in some parts, it is ongoing. KenGen, together with the Ministry of Energy has conducted surface scientific studies in Suswa, Longonot, Eburru, Menengai, Arus and Bogoria, Lake Baringo area, Korosi and Chepchuk, and Paka. Preliminary results indicate significant potential estimated at 200 MW in Longonot, 200 MW in Suswa, and 720 MW in Menengai. Six exploratory wells were drilled at Eburru and analysis show that it can sustain 2.5 MW of electric power. Other high potential areas earmarked for further exploration work include Emurauangogolak, Barrier volcanoes, Namarunu volcanic field, and Badlands

**Table 10**
Planned wind power projects.

| Project | Capacity (MW) | Estimated commissioning date |
|---|---|---|
| Ngong 3 (KENGEN) | 14 | July 2012 |
| Lake Turkana (IPP) | 300 | July 2013 |
| Osiwo wind (IPP) | 50 | July 2013 |
| Aeolus (IPP) | 60 | July 2013 |

*Source*: [42].

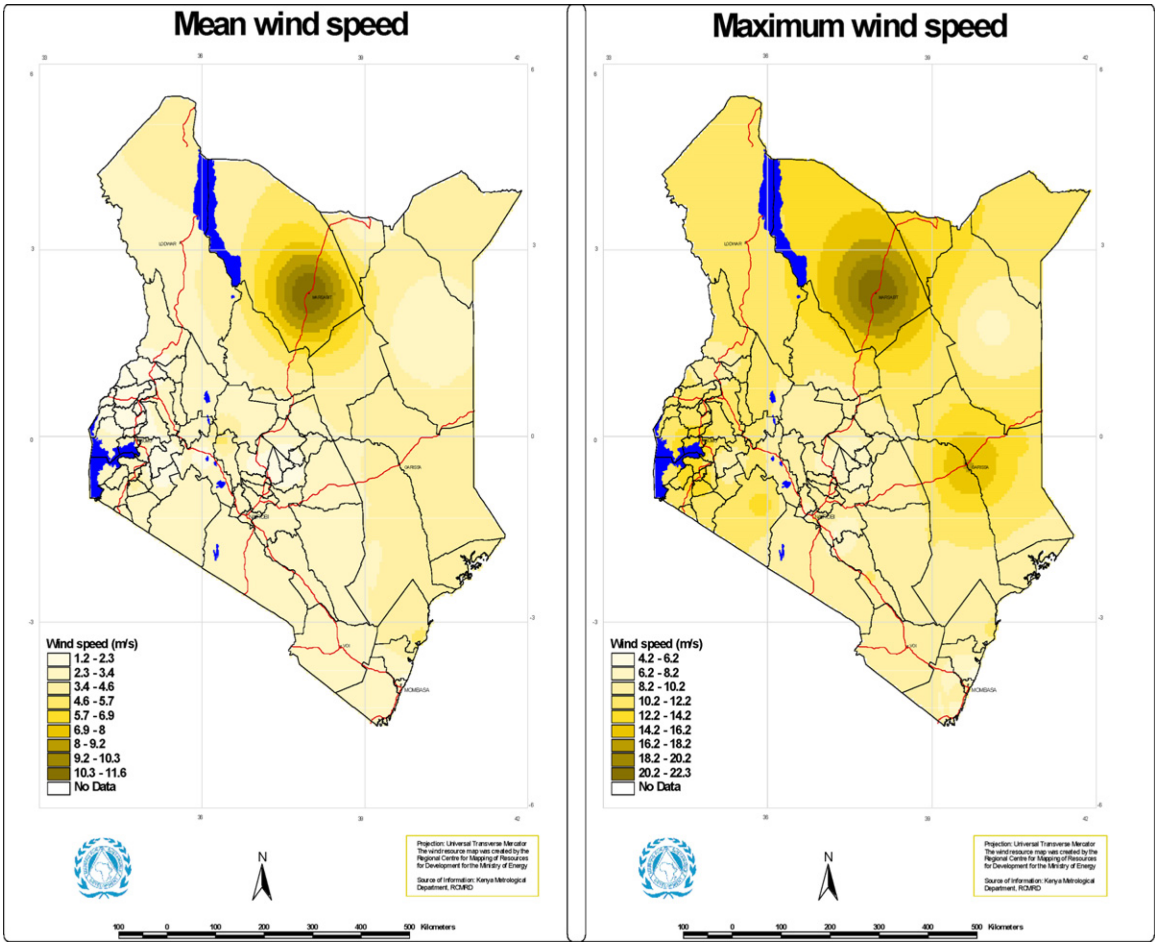



**Fig. 7.** Spatial patterns of the mean and maximum wind speeds in Kenya [39].

Volcanic field and Lake Magadi geothermal area in the South, among others.

*3.5.2. Status of geothermal energy in Kenya*

Kenya was the first country in Sub-Sahara Africa to exploit geothermal based power on a significant scale [44].The Exploration for geothermal resources in Kenya began in 1956 and gained momentum in the 1960s. From 1967, the United Nations Development Programme (UNDP) in collaboration with the then East African Power and Lighting Company Ltd, conducted geological and geophysical surveys in the area between Olkaria and Lake Bogoria. The studies identified Olkaria as the most prospective area, where exploratory wells were drilled, leading to the construction of the first three geothermal power stations, each with a rated power of 15 MW which were commissioned between 1981 and 1985. Exploration and drilling has continued with both private and public sector involvement. Some of the works related to geothermal power generation in Kenya are available in the literature [45–47]. Currently, a total of 163 MW electricity is generated from geothermal resources (Table 11), of which KenGen produces a total of 115 MW, and Orpower4 (an IPP) the remaining 48 MW. Fig. 11 shows the photographs of the two most recent plants. A minor project with a 1.8 MWe binary plant owned by a flower growing company (Oserian flower farm) was commissioned in 2004. Other geothermal related projects that have been established include greenhouse heating at Oserian flower company, geothermal heated Pyrethrum drying at Eburu and swimming pool heating at Lake Bogoria.

Geothermal power has been identified as the least cost source of energy in Kenya and the government has put a lot of focus to facilitate geothermal development. A state-owned Geothermal Development Company Ltd. (GDC) was recently established, to speed up geothermal power production. The GDC is responsible for exploration, drilling and assessment of geothermal resources up to

**Table 11**
Existing geothermal plants in Kenya.

| Station | | Location | No. of units | Rating per unit | Installed capacity | Year installed |
|---|---|---|---|---|---|---|
| Olkaria I | KenGen | Olkaria | 3 | 15 | 45 | 1981 |
| Olkaria II | KenGen | Olkaria | 2 | 35 | 70 | 2003 |
| Olkaria III | Orpower4 | Olkaria | 1 | 13 | 13 | 2000 |
| Olkaria III | Orpower4 | Olkaria | 3 | 12 | 35 | 2008 |
| Sub-total | | | | | 163 | |

*Source*: [13].

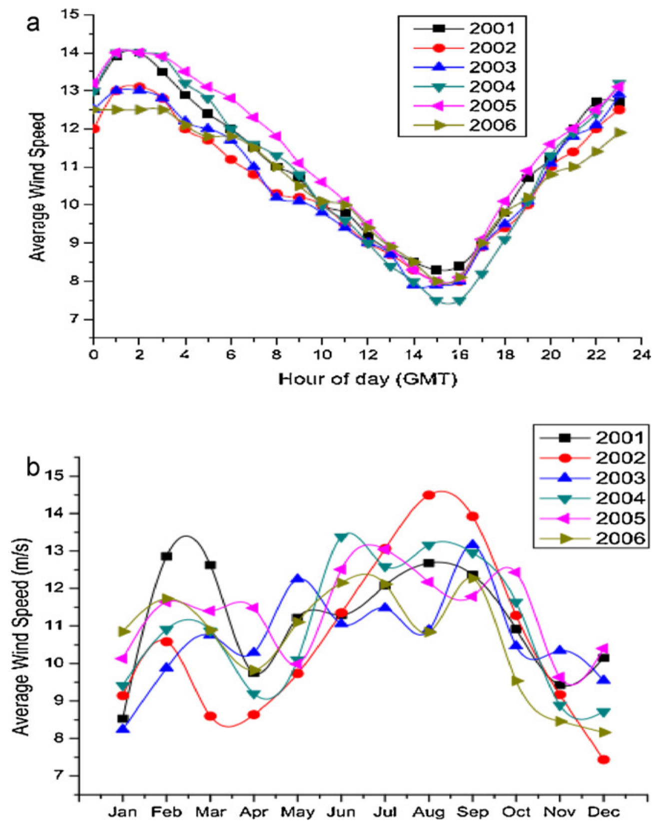



**Fig. 8.** Average wind speed variability in Marsabit, Kenya 2001–2006 (a) hourly and (b) monthly [40].

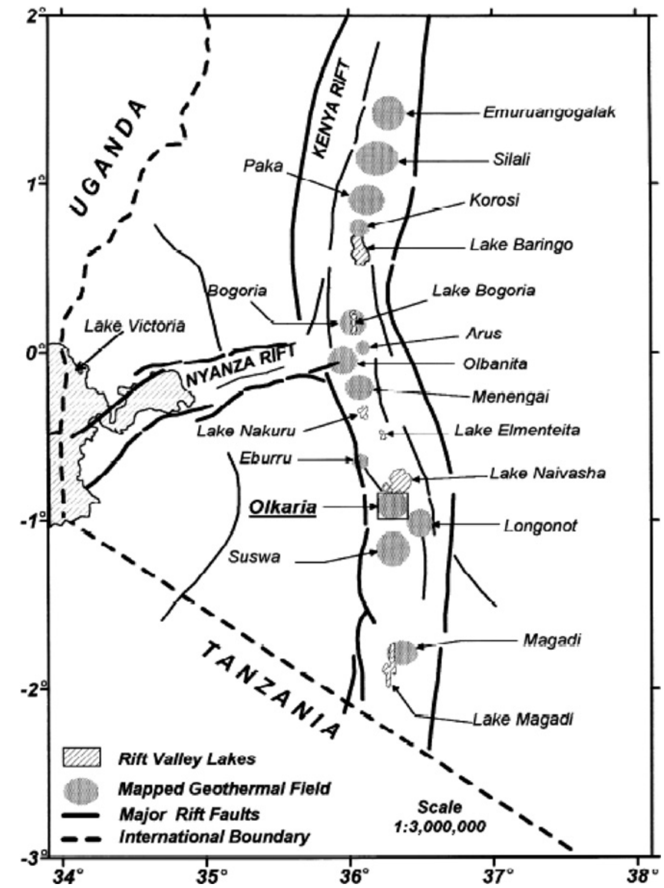



**Fig. 10.** Map of the Kenya Rift Valley showing geothermal potential areas [43].

a point where a clear and sustainable statement of resource potential has been prepared, with sufficient confidence that potential developers would be encouraged to invest in designated generation projects. Under this arrangement developers will be charged for steam, but will be expected to bid for development of power plants through international competitive bidding. The risks associated with geothermal exploration will therefore be covered by the government. GDC is expected to facilitate development of at least 700 MW geothermal capacity in the next 10 years. Table 12 shows the planned geothermal power projects to be commissioned in the near future.



**Fig. 9.** Kenya's first wind farm at Ngong Hills.

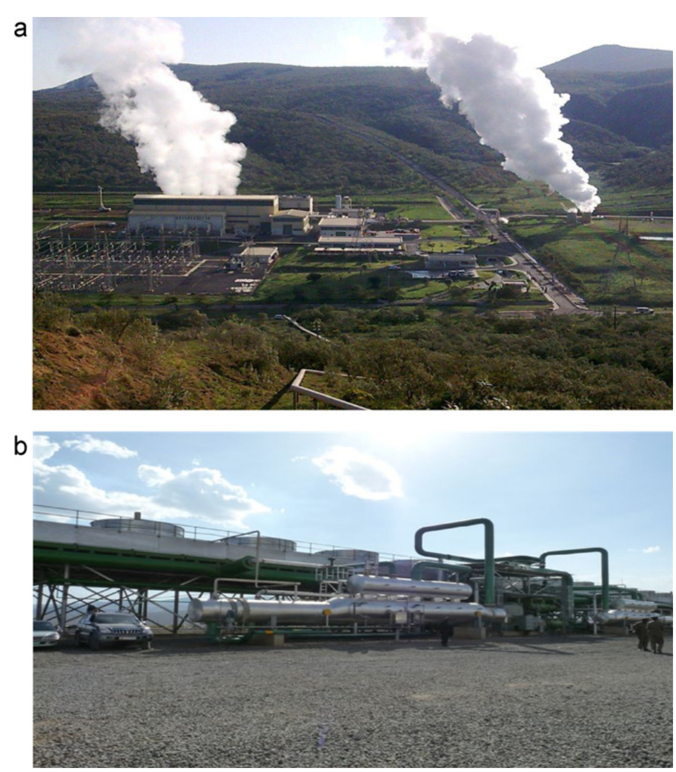



**Fig. 11.** Photograph of geothermal power plants (a) Olkaria II (70 MW) and (b) section of Olkaria III (the first privately funded and developed geothermal plant in Africa).

**Table 12**
Planned geothermal power projects.

| Project | Capacity (MW) | Estimated commissioning date |
|---|---|---|
| Olkaria II 3rd Unit | 35 | June 2010 |
| Eburu | 2.5 | January 2011 |
| Olkaria IV | 140 | January 2013 |
| Olkaria I Units IV and V | 140 | July 2013 |
| Orpower 4 (IPP) | 50 | January 2014 |

*Source*: [40].

## 4. Future outlook and suggestions

Energy is an essential ingredient for socio-economic development and economic growth of any country. Reliable and affordable energy supplies are required to meet the basic human needs such as cooking, lighting, safe drinking water, education, communication among others. The Kenya Government has developed the Kenya Vision 2030 as the country's new development blueprint covering the period up to 2030. The vision aims at transforming Kenya into a newly industrializing, middle income country providing a high quality life to all its citizens by the year 2030. Moreover, the vision aims to achieve a sustained average GDP growth rate of 10% per annum for the next 20 years.

Energy demand, particularly commercial energy tends to fluctuate in the same pattern with the economic performance. This observation is true for Kenya where the real GDP value over the years has tended to move in same trend with commercial energy consumption [48]. Fig. 12 shows the projected electrical energy demand until the year 2030, based on three possible GDP growth scenarios (reference, low and high) presented in the Vision 2030. Taking the low growth scenario, for example, shows that the electricity demand will triple by the year 2020, and will be six times the current demand by 2030. Furthermore, the trend in demand for petroleum fuels may be similar to that of electricity. The demand for wood fuel is projected to rise to about 53.41million tones per year by the year 2020.

Looking at the current energy situation, there are a number of challenges and weaknesses that affect energy supply in Kenya. These challenges are: low access to modern energy leading to high pressure on biomass resources, high cost of energy, demand of electricity is increasing faster than ability to install additional generation capacity, inability by KPLC to connect all customers who are willing to take supply, high cost of rural electrification through

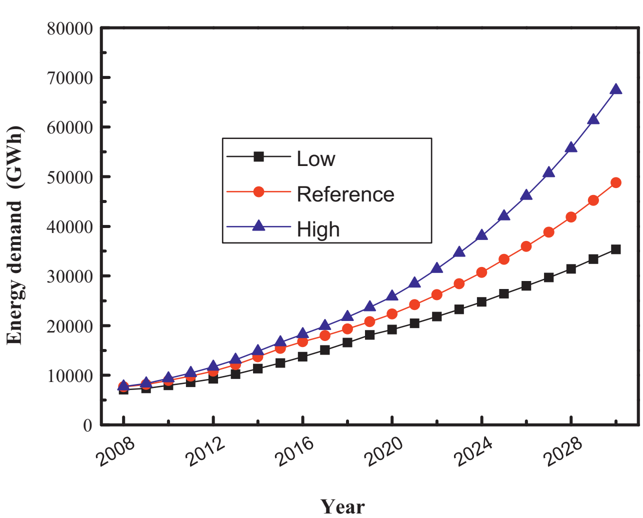



**Fig. 12.** Energy demand forecasts for Kenya: Low scenario, Reference and High scenario 2008–2030 [13].

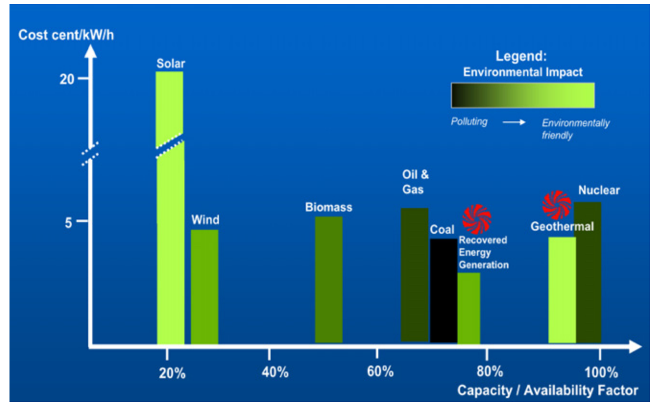



**Fig. 13.** Comparison of power generation options in terms of costs, environmental impacts and availability factors [49].

grid extension due to the scattered nature of settlements; frequent power outages and high system losses, high dependence on imported petroleum fuels, among others. This, therefore, calls for concerted efforts by the government and all stakeholders to address these challenges to ensure an adequate and cost effective supply of energy for economic growth and improvement of quality of life of the citizens, while taking cognizance of the need to protect and conserve the environment.

With regard to the energy supply options, cost of power generation, capacity/availability factors and environmental impacts are among the major factors to consider (Fig. 13). Other important factors include sustainability and the ability to create jobs for the growing populations. Given the abundant availability of geothermal resources in Kenya, geothermal energy is likely to become a preferred contributor of base load power. It is competitive in terms of cost, has high capacity/availability factors and near zero emissions, especially when modern closed cycles which re-inject water back to the earth's crust is employed. Geothermal projects have high capital investments needed for exploration, drilling wells and installation of the plant, but the operating costs are low. The decision by the government to absorb the costs associated with the exploration and drilling of geothermal wells will keep the power tariff low, if the costs are not passed to the consumer. Low power tariffs are necessary to attract investors especially in the industrial sector.

Regarding hydropower resources, although they will continue provide the base load, their future expansion potential may face some challenges. This is because the demand on water resources for other purposes is growing rapidly such as horticulture and other irrigation based agriculture, increased population thus increase demand of domestic and industrial water supply etc. This makes water resources less available in future than has been in the past. Dependability of river waters, as the major source of electric power generation is risky because it in turn depends upon climatic and weather variations, which are unpredictable at times and quite uncontrollable. Measures should however be taken to safeguard river water resources, such as maintenance of enough forested area to ensure rainfall, soil erosion control programmes over the catchments areas to decrease rate of dam siltation.

Wind energy will also play a greater role in the country's energy mix. However, the challenge which needs to be addressed is the low capacity factor of wind power. Since wind does not blow 100% of the time, the grid will have to be able to handle the instability. At present, few grid systems have a penetration of wind energy above 5% such as Denmark (over 19%), Spain and Portugal (over 10%), Germany and republic of Ireland (over 6%) [50]. Higher proportion of wind power is likely to cause grid management problems

and also will require a high reserve generation. The development of wind power in Kenya should therefore be concurrent with other sources with higher capacity factor which can fill the gaps.

A lot of interest in biodiesel has developed across the globe in the recent past because of its potential to stimulate economic growth, reduce carbon-dioxide emissions and hence improve the environment and reduce dependency on imported oil. There exist immense opportunities for biodiesel development in Kenya. About 80% of the land consists of arid and semi-arid land in which some biodiesel feedstock such as jatropha can thrive well without threatening the country's food security. This provided a chance to decrease the dependence on expensive foreign oil, create the much needed jobs, and improve the economy, especially for farmers who will growing the feedstock.

With regard to biomass, there is a resurgence of interest in biomass energy in recent years because it is perceived to be carbon neutral source compared to net carbon emitting fossil fuels which are known to cause global warming. Several negative impacts associated with the use of biomass are known which include: heavy labour in searching, cutting and carrying wood, usually by women and girls; emission of products of incomplete combustion such as carbon monoxide, nitrogen, sulphur oxides, as well as particulate matter, and, the health effects of particulate matter leading to acute respiratory infections, identified as the leading cause of illness in Kenya and other developing countries. There is need for more investment in research and development of improved biomass stoves in order to enhance their efficiency and to reduce indoor air pollution. On the other hand, given the high biomass deficit in the country, there is need to improve access to LPG as an alternative to biomass by implementing appropriate pro-poor policies.

Concerning solar energy, the existing potential is enormous and will play a greater role for energy generation in the future. Furthermore, the places with the highest solar radiation are located in arid areas with low agricultural potential and sparse population, hence large solar systems such as PV and concentrated solar thermal etc. can easily be accommodated. Although the unit cost of solar electricity is still high, there are expectations that this will continue to decrease with time and be economically feasible. There is therefore need for research, development and demonstration projects for raising awareness and understanding of both technical and non technical aspects of the technologies.

## 5. Conclusion

Kenya has a liberalized energy sector and has made significant progress in the formulation of policies which favors the development of renewable energy. It has the world's highest household solar ownership rate with about 30,000 small (20–100 W, per household) systems sold per year. In addition, Kenya's electricity power mix is among the most sustainable in the world, with 80% of electricity coming from renewable sources (mainly from hydro and geothermal).

However, the energy sector is facing a lot of challenges mainly resulting from high dependence on imported oil and wood biomass. The oil import bill in 2008 consumed 55% of the country's foreign exchange earnings from exports. On the other hand, the over reliance on biomass has exerted considerable pressure on the remaining forest and vegetation stocks, thereby accelerating the processes of land degradation. Moreover, despite the abundance of potential and a strong growth in demand for electricity, the country faces constraints in satisfying electricity demand. At the national level, only 18% of the households have access to grid electricity. The access is much lower in rural areas where only 4% of the households have grid electricity

A substantial proportion of renewable energy resources are unexploited, which provides opportunity to increase the proportion of green energy in the power mix and to provide clean energy to the citizens. Of the potential renewable sources, Kenya has harnessed only about 30% of its hydropower sources, approximately 4% of the potential geothermal resources and much smaller proportions of proven wind and solar power potentials. Furthermore, a large potential exists for the development of biomass based energy such as biogas, biodiesel and power generation form bagasse.

The strong growth in energy demand and favorable legislation provides excellent opportunities for private investors to invest in renewable energy project in Kenya.

## Acknowledgements

Assistance from Chinese government through the Chinese Scholarship Council (CSC) is hereby acknowledged.

## References

[1] Government of Kenya. Economic survey, 2009: Ministry of Planning and National Development. Nairobi, Kenya: Government printer; 2009.
[2] United States. The world Factbook 2009, Central Intelligence Agency; 2009.
[3] Government of Kenya. Economic survey, 2008: Ministry of planning and national development. Nairobi, Kenya: Government printer; 2008.
[4] IEA. Energy Balances of non-OECD Contries, Paris: International Energy Agency; 2007.
[5] Government of Kenya. Kenya Investment Conference: Ministry of Planning, 22–23rd July, 2008.
[6] UNDP. Kenya Energy Atlas: Global Village Energy Partnership. Nairobi Kenya; 2005.
[7] KPLC. Annual Report and Accounts: 2007–2008. Kenya Power and Lighting Company (KPLC); 2008.
[8] Republic of Kenya. Millenium Development goals: Needs Assessment Report. Ministry of Planning and National Development; 2006.
[9] Government of Kenya. Sessional Paper No.4 of 2004 on Energy; 2004.
[10] Government of Kenya. Energy Act 2006. Ministry of Energy; 2006.
[11] Government of Kenya. Feed-in-tariffs for Renewable Energy Resource Generated Electricity: Guide for Investors. Ministry of Energy; 2008 [http://www.energy.go.ke]).
[12] Njiraini J. New tariff lures renewable energy investors, E. A standard 30th March, 2010.
[13] Government of Kenya. Least Cost Energy Development plan: 2009–2029. Ministry of Energy; 2008.
[14] Ministry of Energy. Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments: Final Report. KAMFOR Company Limited; 2002.
[15] Ann I. Rocket mud stoves in Kenya. Boiling Point No 53; 2007.
[16] Felix ter H., Kai S. Domestic biogas in Africa; a first assessment of the potential and need [Draft/Discussion paper]. Biogas for better life: an African Initiative conference, May 2007.
[17] Simalenga TE, Gohl B. Tubular plastic bio-digester: design installation and management. Harare: FARMESA; 1996.
[18] ETC UK, Biogas for better Life: An African Initiative, A feasibility study, October 2007.
[19] Endelevu Energy and ESD. A roadmap for Biofuels in Kenya: opportunities and obstacles. A study commissioned by Ministry of Agriculture and GTZ. May 2008.
[20] Joseph MK. Biodiesel Research and production in Kenya (2007). www.ars.usda.gov/meetings/Biofuel2007/presentations/IP-A/Keriko.pdf [accessed on 10.11.09].
[21] Kalua I. Stakes constraints of bio-fuels cultivation in East Africa. Green Africa Foundation-www.greenafricafoundation.org.
[22] NEMA. Kenya's Climate change Technology needs assessment report under the United Nations framework convention on climate change. November, 2005.
[23] Acres International Ltd. National Power development Plan 1986-2006: Kenya; 1987.
[24] GTZ Eastern Africa Energy resource base [http://regionalenergy-net.com].
[25] www.energy.go.ke.
[26] Schillings C, Mayer R, Trieb F. High resolution solar radiation assessment for Kenya: SWERA Report. October, 2004.
[27] Daniel MK. What Solar Power Needs Now, Renewable energy world, August, 2007 [http://www.renewableenergyworld.com/rea//news/article/2007/08/what-solar-power-needs-now-49617].
[28] Martinot E, Chaurey A, Lew D, Morreira JR, Wamukonya N. Renewable energy markets in developing countries. Annual Review of the Energy and Environment 2002;27(1):309–48.
[29] Acker RH. The quiet (energy) revolution: analysing the dissemination of photovoltaic power systems in Kenya. Energy Policy 1996;24(1):81–111.
[30] Van der Plas RJ, Hankins M. Solar electricity in Africa: a reality. Energy Policy 1998;26(4):295–305.

[31] Jacobson AE. Connective Power: Solar Electricity and Social change in Kenya. PhD Thesis. Berkeley: University of California; 2004.
[32] Rabah KVO. Integrated solar energy systems for rural electrification in Kenya. Renewable Energy 2005;30:23–42.
[33] Jacobson A, Kammen D. Engineering institutions and public interest: evaluating product quality in the Kenyan solar photovoltaic industry. Energy Policy 2007;35:2960–8.
[34] Hankins M. A case study of private provisions of photovoltaic systems in Kenya. In Energy services for the world's poor. World Bank Energy Sector Management assistance programme (ESMAP), Washington DC.
[35] Duke RD, Graham S, Hankins M, Jacobson A, Kammen DM, Osawa B, et al. Field performance evaluation of amorphous silicon (a-Si) photovoltaic systems in Kenya. In: Methods and measurements in support of a sustainable commercial Solar Energy Industry. 2000.
[36] ESDA Study on PV market chains in East Africa: Report for the World Bank by Energy for Sustainable Development Africa (ESDA), Nairobi, Kenya. October, 2003.
[37] Carl E. Rural milk preservation with the ISAAC ice maker. Energy for Sustainable Development 2009;13:287–91.
[38] Asani GC, Kinuthia JH. A newly formed jet in Northern Kenya (Turkana Channel). In: 1st International conf. on southern meteorology. 1984.
[39] Ministry of Energy. Wind Atlas for Kenya 2004.
[40] Kamau JN, Kinyua R, Gathua JK. 6 years of wind data for Marsabit, Kenya average over 14 m/s at 100 m hub height; an analysis of the wind potential. Renewable Energy 2009, doi:10.1016/j.renene. 2009.10.008.
[41] Harris M. Disseminating wind pumps in rural Kenya-meeting rural water needs using locally manufactured wind pumps. Energy Policy 2002;30: 1087–94.
[42] KPLC. Annual Report and Accounts: 2008-2009. Kenya Power and Lighting Company (KPLC); 2009.
[43] Simiyu SM, Keller GR. Seismic monitoring of the Olkaria Geothermal area, Kenya Rift valley. Journal of Volcanology and Geothermal Research 2000;95:197–208.
[44] AFREPREN and FWD. Success story-Geothermal power Generation in Kenya. [www.e-parl.net/eparlimages/general/pdf/081024%20East%20Africa%20-Geothermal%20Toolkit.pdf] [accessed on Dec. 2009].
[45] Tole PM. Geothermal energy research in Kenya: a review. Journal of African Earth Sciences 1996;23(4):565–75.
[46] Mathu EM, Davies TC. Geology and environment in Kenya. Journal of African Earth Sciences 1996;23(4):511–39.
[47] Mariita NO. The impact of large-scale renewable energy development on the poor: environmental and social impact of geothermal power plant on a poor rural community in Kenya. Energy Policy 2002;30:1119–28.
[48] KIPPRA. Strategies for securing energy supply in Kenya: Discussion paper No. 74. September 2007.
[49] Ormat Technologies Inc., http://www.tase.co.il/NR/rdonlyres/26808B95-5853-43E3-9570-7FF4FBE49B61/0/20070221_ILOpportunity2007London_Ormat.pdf.
[50] Windpower: http://en.wikipedia.org/wiki/Wind_power.